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EXPLOSIVES RESEARCH & DEVELOPMENT ESTABLISHMENT

REPORT No. 30/R/49

A Miniature Proofstand for Precise Physical Measurements on Rocket Motors

L. A. Wiseman and H. Ziebland

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A Miniature Proofstand for Precise Physical Measurements on Rocket Motors

By

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SUMMARY.

A miniature proof-stand has been constructed for fundamental studies of the properties of rocket flames. The rocket motor gives a thrust of 30 lbs. and is cooled so that propellants with the highest combustion temperatures can be used.

The design is described in detail and suggestions for future developments are made.

1. INTRODUCTION.

The principles of the design and construction of rocket motors operating with conventional liquid propellants have been developed up to now on a practical basis. Future developments, such as improvements in efficiency of existing propellants and the utilisation of new very high performance propellants require a much sounder theoretical basis. Thus, for example, all heat transfer calculations are based essentially on formulae which are extrapolations from much less severe conditions, lower temperatures and pressures, and lower flow velocities.

Most rocket motor proofstands are designed for the evaluation of propellant performance in motors of from one hundred pounds to several thousand pounds thrust. Experience has shown that it is impossible to combine fundamental work with routine testing. Further, the flexibility of such a proofstand is limited; it may be desirable for instance, to use much higher combustion pressures (100 ats. or more) for heat transfer studies and this is not easily practicable in large motors because of constructional and operational difficulties. In many cases, moreover, long runs may be necessary and this involves large quantities of propellants. Finally certain investigations require valuable and static equipment, which should not be moved once it has been set up. This is clearly not desirable on large proofstands where, apart from the greater risks of destruction sensitive equipment when not in use is a handicap.

For these reasons miniature proofstands, each designed for one specific type of fundamental research, have been constructed in such a way as to give a wide range of operating conditions.

2. GENERAL DESIGN CONSIDERATIONS.

2.1. Propellants.

As the object of the work proposed was the investigation of high velocity hot gases and flames, it was clearly desirable to choose a propellant system which gave the smallest hazards and least difficulty in handling. Of the known oxidants gaseous oxygen was the obvious choice, because it is completely stable, non-corrosive and can be handled by well established techniques. The standard fuel chosen for the initial work was a high grade aero engine. Diesel oil because it gives high combustion temperatures, is safe to manipulate and has been used as a rocket fuel extensively(1). Rather complete thermodynamic data is available for this propellant system (2.3).

2.2. Type of Motor.

Most types of motors which have been developed have operated at a combustion pressure of about 20 ats. and this was therefore accepted as a standard pressure for the first miniature motors. Part of the work planned with this motor was an investigation on the attenuating properties of flames. The smallest Radar equipment was for K-band radiation (about 1.4 cm wave length) which requires a flame diameter of at least 2 cms for satisfactory measurement. This dimension is effectively the diameter of the exit of the expansion nozzle and, together with the pressure ratio for the expansion process, determined the throughput of the propellant and thus the thrust of the motor, which amounts to about 30 lbs. With this information it was

/immediately

immediately possible to design motors on the basis described by Ziebland (1). In order to give maximum flexibility in operation, water cooled motors were designed for operation at combustion pressures up to 40 ats.

2.3. Ignition of Propellants.

Ignition can be achieved in 3 ways :-

(a) by self-igniting fuels.

(b) by solid propellants or pyrotechnic igniters.

(c) by spark ignition.

Since it might be necesssary to have repeated operation at short intervals solid propellant or pyrotechnic igniters were eliminated. Spark ignition had not been developed sufficiently and in any case the risk of the electrodes being burnt away was large. Therefore a self-igniting fuel was selected and experience in Germany had dhown that zinc-diethyl was very reliable with gaseous oxygen and relatively easy to make. A fuel circuit was designed to allow a small quantity of zinc-diethyl (about 40 ccs.) to enter the main fuel line, closely followed by the fuel itself.

2.4. Mechanism of Control.

The basic principle of the control system was that it should be as flexible as possible and yet be capable of operation by the scientific personnel without additional auxiliary labour. Since these proofstands were designed as research tools and therefore would be operated by different scientists depending on the type of measurements required, it was essential that the control system should be compact, uncomplicated and well protected against possible errors in operation.

Following these ideas it was clear that the motor, once controls were set, should be capable of repeated operation from one master control, preferably by a simple device such as an electric switch.

Since the motors were intended for use with static equipment (interferometers, spectroscopes etc.) the desired flexibility must also allow movement of the rocket motor while in operation.

2.5. Safety.

The main sources of danger are bursts in high pressure lines and burning out of the rocket motors. These can lead to fragments, fires and possibly a gas phase explosion, but not to a condensed phase detonation as the oxidant used is always in the gaseous state. Adequate protection of the scientist operating the controls (considering the small quantities of propellants involved) would be given by a concrete wall separating the motor and its propellant supply from the control panel. All high pressure lines for oxidant, fuel and self igniting liquid must be situated on the motor side of the protective wall.

/General layout of Proofstand.

3. GENERAL LAYOUT OF PROOFSTAND.

The general considerations of Section 2 are a sufficient basis for the detailed design which is described in this section. It can be divided into a number of more or less independent circuits.

3.1. Oxygen Circuit.

The purpose is to supply oxygen gas at a predetermined pressure and temperature to the rocket motor. A pipe circuit diagram is shown in fig.1.

The oxygen is supplied from cylinders at a pressure of 120 ats. The cylinders are connected through a distributor block 1 to the oxygen circuit. The gas goes from this block to the high pressure coil 2a of the heat exchanger 2, in order to keep the temperature of the gas above the freezing point of water. This is necessary because the rapid expansion in the cylinders is practically adiabatic and any solid (ice) in the gas stream may lead to failure of valves in the circuit. The gas then enters the reducing valve 3, which controls the rate of feed of the oxygen into the motor. Before proceeding to the flowmeter 4 (orifice type) the gas is led back through the low pressure coil 2b of the heat exchanger 2, so that the temperature of the oxygen when it passes the flowmeter is practically that of the heating water used in the heat exchanger, and almost constant. The gas flow is started or stopped by a high pressure solenoid valve 5, and is led into the combustion chamber through a non-return valve 6. A hand operated vent valve 9 allows the oxygen pressure up to the reducing valve 3 to be released.

The heat exchanger is of standard design and consists of a high pressure coil 2a and a low pressure coil 2b of a large surface area so that the oxygen gas is brought practically to the temperature of the heat exchanging liquid (mains water) even at the highest rates of flow.

The reducing valve 3 is of American design (Grove Regulator Co., California) made under license in this country by Fluid Control Ltd. The flow is controlled by a diaphragm, loaded by an auxiliary gas pressure according to the flow required. Nitrogen is used for this purpose, the flow of which to the diaphragm of the oxygen reducing valve 3, is determined by the control valve 3a. This arrangement allows remote control of the main oxygen flow from the control panel and has been found very satisfactory in practice.

The control panel fig.5. contains the pressure gauge 1a for the input oxygen pressure, the pressure gauge 4a for the pressure at the flowmeter, the control valve 3a, and the temperature indicator 4b for the gas temperature at the flowmeter. The solenoid valve 5 is operated by the main control switch (see Section 3.4).

The flowmeter is at present under construction. It consists of a standard orifice, the differential pressure across which is converted into a mechanical movement by a bellows assembly. This movement operates a potentiometer which allows of remote indication.

The check valve 8 and the hand-operated valve 7 on the control

/panel

panel are part of the nitrogen flushing system described in section 3.44.

3.2. <u>The Fuel and Ignition Circuit</u>:

As both fuel and ignition material are liquids and the quantities involved are small, high pressure nitrogen gas is used to feed them into the motor. A pipe diagram of the circuit is shown in fig.2.

The high pressure nitrogen is led from cylinders through a distributor block 10 into the pipe circuit. The control valve 11 maintains a pre-selected nitrogen pressure on the fuel cylinder 12 and ignition fuel cylinder 13. A solenoid operated valve 14 starts and stops the nitrogen flow to these cylinders and releases the pressure on them automatically when it is switched off after the completion of a run. To start, the ignition fuel is led from the cylinder 13 through the two-way solenoid valves 15 and 16 into the main line, and is followed closely by the fuel when valve 15 is switched into its other position. The two-way valve 16, when there is no pressure in the system, shuts off the main line from both cylinders 12 and 13. It does not open the main line to the ignition fuel until a certain pressure is reached in the ignition fuel cylinder 13. This pressure is determined by a pressure operated relay 17, which closes and opens the electrical circuit for valve 16.

A run is started by opening the high pressure solenoid valve 5 in the oxygen circuit (fig.1), and the nitrogen solenoid valve 14 in fig.2. Because of the self-igniting fuel, no air or oxygen must be in the main fuel line at the start of a run. This is achieved by an initial flow of nitrogen through valve 16. It flushes the fuel line free from air and prevents any oxygen flowing into it from the combustion chamber. As soon as the pressure exceeds 5 ats. in the ignition fuel cylinder, valve 16 is operated from the relay 17, and allows the ignition fuel to enter the main line.

When leaving the cylinder 12, the fuel is first led through a filter 18. A flow measuring system, 19, identical with the one described in the oxygen circuit, will be built into the circuit as soon as the preliminary tests have been completed satisfactorily. Before entering the combustion chamber the fuel passes through a non-return valve 20 (which prevents nitrogen from getting back into the fuel circuit, when the line is flushed with nitrogen after a run), through the manually operated valve 22 and the non-return valve 21. The latter stops high pressure oil from entering the flushing line during a run.

It is known that both ignition fuel as well as Diesel-oil, which is the standard fuel on the proofstand described, absorb a large volume of gas rather quickly at high pressures. This effect, which depends largely on time and the gas pressure above the liquid surface, would cause a varying and unknown alteration in the density of the liquids and would therefore lead to errors in the flow measuring system. For this reason it was decided to separate the liquid and the pressurising gas by pressure tight pistons 12a and 13a. The contacts 12b and 13b which are operated by the pistons, indicate when the piston is at the top and bottom position, that is when the cylinder is "full" or "empty", by means of signal lamps on the control panel. The total capacity of the fuel cylinder is about 2000 ccs. which is sufficient for a run of

/100

100 seconds at a combustion chamber pressure of 20 ats. with the stoichiometric mixture ratio and a thrust of about 30 lbs. The volume of the ignition fuel cylinder 13 is considerably smaller, only 140 ccs., allowing on the average, 3 to 4 ignitions. The piston of the fuel cylinder is fitted with an extension rod which operates the "empty" signal before the piston has reached its lowest position. Assuming standard conditions, i.e. 20 ats. combustion pressure, stoichiometric mixture ratio and 30 lbs. thrust, there would be a time interval of about 10 secs., before the fuel cylinder was completely empty. Within that time the run has to be stopped in order to prevent the flame from entering the fuel injection system after the delivery of fuel has ceased.

Refilling of the fuel cylinder is done by a hand-operated piston pump 23 from a fuel storage tank. The fuel enters the cylinder past a three-way cock 24 and a high-pressure stop valve 25. The three-way cock enables the pressure to be released after the filling and the fuel cylinder to be drained.

The ignition fuel cylinder is refilled in a similar way. A storage vessel is pressurised by nitrogen gas and the liquid is fed into the cylinder through the stop valve 26.

Both cylinders 12 and 13 are similar in design and differ mainly in size. Fig.3 shows a cross section through the ignition fuel cylinder 13.

The two-way solenoid valves 15 and 16 are of normal pattern. Valve 15 can only be operated when there is little or no pressure difference between the two cylinders 12 and 13. This feature, being part of the safety arrangements, will be discussed in Section 3.43. After the completion of a run, valve 16 is switched back into its starting position thus connecting the main fuel line with the nitrogen flushing line. Owing to its design, a small amount of fuel then enters the nitrogen line. An oil trap, 27, with a drainage cock 28, prevents oil from reaching the valve 14, by leakage.

The instrumentation on the control panel fig.5, includes a pressure gauge 29 for the nitrogen entry pressure, and a gauge 30 for the reduced pressure acting on the pistons of the cylinders. The fuel pressure and its temperature, near the flow measuring orifice, are indicated by the pressure gauge 31 and the resistance thermometer 32. At a later stage, a remote indicating differential pressure gauge 33 will be added to determine the rate of flow of the fuel.

The manually-operated reducing valve 11, which maintains the pre-set pressure in the cylinders 12 and 13, is also fitted on the control panel, together with the signal lamps which indicate the "full"and "empty" positions of the pistons in these cylinders.

A vent valve 33a on the nitrogen distributor block 10 allows the line to be vented.

3.3. The Coolant Circuit:

The high thermal loads on the combustion chamber and the expansion nozzle obtained with the propellant combination oxygen-Diesel oil, require a suitable coolant and an efficient cooling system.

/For

For general purpose experiments water has been chosen as the most suitable coolant, but provision has been made in the layout of the circuit, as shown in fig.4, for the use of other liquids as coolants.

The coolant is fed from a storage tank into a centrifugal pump which delivers it at a pressure of about 35 ats. through the main stop valve 34 and the filter 35 into the distributor block 36, whence four independent cooling lines branch off for the cooling of a corresponding number of sections on the rocket motor. At present, only two of them are in use; one for the cooling of the actual combustion chamber, the second for the cooling of the expansion nozzle. After passing through the cooling channels in the combustion chamber and the venturi, the coolant is brought back over a pressure operated relay 37 and a throttling valve 38 into a collector block 39, from which it is led back, through valve 40, through a common line into the coolant tank.

The adjustable throttling valve 38 fulfils a dual purpose. First it controls the rate of flow of the coolant in that particular line, and secondly it keeps a back pressure in the exit line sufficiently high to prevent vapour formation in any part of the cooling channels of the motor. The coolant water relay 37, which is described in more detail in a later section on safety devices, shuts off the main propellant valves if the rate of flow of the coolant drops below a level which is regarded as a safe minimum, or prevents the propellant circuit from being switched on if there is an insufficient coolant flow or none at all.

At a later stage a flowmeter 41 will be built into the entry side of each cooling line with remote indicating differential pressure gauges 42, similar to those mentioned in the description of the propellant circuits. A resistance thermometer 43 allows the entry temperature of the coolant to be read on the control panel for calibration purposes. The entry pressure, which is constant for all lines, is indicated by the pressure gauge 44; the four different exit pressures by the gauges 45.

In the actual lay-out, valves 34 and 40, the filter 35, and the connector blocks 36 and 39 with the adjusting valves 38, are built together as one unit which is fitted on the control board to allow manual control and adjustment.

3.4. Safety Devices:

The devices described in this section are partly for the purpose of minimising the results of the usual types of proof-stand accidents, e.g. bursting of high pressure lines, but primarily to prevent accidents from errors in operation. As a general principle, all pipe lines to measuring and control instruments on the control panel are filled either with nitrogen or a non-reacting fluid.

3.41. Master Control:

As all the valves in the propellant feed lines are operated electromagnetically, it is possible to have a single switch 46 (fig.5), which is itself controlled by a key switch 46a, as a master control. This key switch has two positions. Only in the "off" position can the key be inserted and extracted. In the "on"

/position

position the energising power supply for operating the solenoid valves is switched on. The energising voltage is shown by the voltmeter 47 and the current by the ammeter 48; the signal lamps 49 and 50 show whether the ignition fuel cylinder and the main fuel cylinder are full, empty, or partially full.

The single switch 46 has three positions; null position, ignition and main fuel. When it is switched to the "ignition" position, valves 5 in the oxygen circuit and 14 in the nitrogen circuit are opened and after the relay 17 has energised the two-way-valve 16 (see section 3.2 for details of operation), the ignition fuel can flow into the combustion chamber. The switch is then manually moved to the "fuel" position whereby the two-way valve 15 is energised, thus closing the ignition fuel line and opening the main fuel line at the same time. The run is stopped by turning the key switch 46a to the "off" position, as a result of which all solenoid valves are closed. It should be stressed that the starting circuit can only be energised when the single switch 46 is in the "null" position, e.g. if the switch is in the "ignition" or "fuel" position when the key switch 46a is turned to the "on" position no power is supplied to the solenoids. This is achieved by electrical blocking relays.

In this way the sequence, in which the valves are opened, is strictly controlled so that a run can be started only from the "null" position.

3.42. Cooling Water Relay:

If the rate of flow of the cooling water falls below that adequate to maintain the cooling of the motor, either for mechanical reasons (blockage in the line etc.), or because the coolant water was not turned on, the motor will burn out. In order to avoid this, each cooling line contains a relay 37 (fig.4) in the outlet line which remains open only above a pre-set differential pressure across an orifice, i.e. above a minimum rate of flow. Unless this relay is open no power can be supplied to the electrical circuit and thus no solenoid valves can be opened or kept open whatever the position of the master control.

3.43. Control of Fuel Supply:

As described in section 3.2, the two-way valve 15 determines whether the ignition fuel or the main fuel flows into the combustion chamber. When not energised, this valve is open to the ignition fuel. It cannot open to the main fuel until the pressure difference between the fuel cylinder 12 and the ignition fuel cylinder 13 is below 10 p.s.i. as the valve 15 will not change into its other position with a pressure difference greater than this amount across it. This means that, if the main fuel pressurising circuit is blocked, only igniting fuel can enter the motor but, if the ignition fuel pressurising circuit is blocked, neither ignition nor main fuel can enter the motor, i.e. either ignition occurs, or, if it fails, no combustible mixture of atomised fuel with gaseous oxygen is ejected from the motor. The ejection of such a mixture is also impossible if the ignition fuel cylinder is empty since no pressure can be built up in the line to valve 15.

/3.44.

3.44. Flushing System:

There are two nitrogen flushing systems, one manually controlled, the other automatic. The automatic system comes into operation at the beginning of a run. When the master control is switched to the ignition position valve 14 is opened and nitrogen can flow through valve 16 along the fuel line into the motor. This ensures that there is no oxygen or air left in the fuel circuit. When the pressure reaches about 5 ats., the relay 17 comes into operation and valve 16 changes position so that the ignition fuel can enter the combustion chamber.

At the end of a run all the circuits can be flushed with nitrogen by the manually controlled valve 7 for the oxygen circuit, and 22 for the fuel circuit. In this way, all the piping is made ready for the next run or safe for inspection.

4. STAND FOR ROCKET MOTORS.

For heavy static equipment such as interferometers, spectrometers etc., considerable time and effort is required to obtain satisfactory optical alignment. In the case of measurements at different cross sections of the exhaust jet it seemed to be more practical to carry out the necessary relative movements to the measuring instrument by moving the motor, or rather, the stand of the motor which is rigidly connected with it. Such an adjustment of the relative position of the motor is also required during a run; thus the controls must be operated from the control panel.

Three directions of movement, at right angles to one another (rectangular coordinate system) permit any point in a certain space to be reached. One direction coincides with the axis of the motor and thus with the axis of the gas jet. According to most experimental requirements, the second main direction is the vertical one; thus the third coordinate lies in a horizontal plane, determining the horizontal distance from the jet axis.

For many measurements and investigations, because of the rotational symmetry of the gas jet, positional adjustments will only be necessary in the vertical plane through the jet axis. Therefore, remote controlled operation of the adjustment during a run is provided only for the vertical and horizontal movements in this plane, while the traversing movement is manually operated before or after the run.

These principle requirements of movement combined with the necessity for facilitating the disassembly and adjustment of the mounting of the actual motor, led to the design of a three-coordinate rocket motor stand for the miniature proofstand, which will now be described in detail.

The entire stand for the motor, shown in assembly in figs. 6a and 6b, consists of an adjustable clamping device I, for the motor itself mounted on the head of a pendulum support II, which is rotatable about the axis P-P. The pendulum support is fitted on the cross-slide III, which itself again rests on a vertical adjustable column IV.

The clamping device for the rocket motor (fig.7) consists mainly of a bottom clamp 1 mounted on the top end of the pendulum and a detachable top clamp 2. Both are shaped prismatically inside in order to take the cylindrical casings of the motors. A fibre lining 3 on their surface provides protection against damage to the casing. By means of the clamping bolts 4 and the nuts 5, the

/top

top clamp 2 can be pressed against the motor. The bolts 4 are of adequate length to take motor casings of various diameters.

It was necessary to make the clamping device so that it was adjustable in order to allow for perfect alignment of the axis of the motor with the directions of movement of the cross-slide III in figs. 6a and 6b. For that purpose, the bottom clamp 1 rests in the pivots 6 and 7. Pivot 6 is mounted in the top part of the pendulum support while pivot 7 rests in the bottom clamp 1. They are connected by the cross piece 8. Pivot 6 allows a tilting movement in the vertical plane for making the centre line of the motor horizontal, while movements around pivot 7 allow the axis of the motor to be brought into alignment with the axial direction of movement of the cross slide. The necessary adjustments are transmitted to the bottom clamp 1, through the bolt 9, by means of two manually operated spindles. By turning the tubular nut 10 the two bolts, 11 with right hand, and 12 with left hand thread, are moved in opposite directions thus causing an upward or downward movement about pivot 6. Once the horizontal position has been attained, the lock nut 13 fixes the adjustment. The top end of bolt 11 rests in a self-aligning ball race to allow free movement in all directions, while the forked end of bolt 12 is fitted with a bush having a female thread. By turning the handwheel 14, which is connected with the spindle 15, a traversing movement about pivot 7 can be carried out. To avoid unwanted slackness in the mounting owing to the various pivots and joints, the adjustment of the clamping device can be secured with lock screws 16. Figs. 10 and 14 show the clamping device, together with rocket motor RM.I or RM.II.

The pendulum support consists of a streamlined, thin-walled steel tube 17, part way through which some of the pipe-lines going to the motor are led. On its top end a square light alloy block 18 serves as support for the adjustable clamping device. The bottom end of the steel tube is screwed on to a yoke 19 (figs.8a and 8b), which contains the bearings 20 (self-aligning ball-races), for the two pivots 21 mounted on each side of the cross slide. A U-shaped frame 22 is screwed on to the rear.of the yoke. On its bottom end a carriage 23 can be moved along guides. This carriage contains the thrust bolt 24 for transmitting the thrust to the thrust measuring device, a simple liquid-filled bellows assembly. By moving the carriage 23 with the help of the spindle 25, the distance "A" in fig.8a can be varied within the ratio 1:2. The force actually applied to the thrust measuring device depends on the ratio of the distance of the centre line of the rocket motor from its pivoting point (distance "B" in fig.8a) to the distance of the thrust bolt 24 from the vertical line through the pendulum pivot (distance "A" in fig.8a). As distance "B" remains practically constant the thrust applied to the bellows can be varied within the same range as the distance "A". The alteration of this leverage is essential to bring the pressure in the bellows within the range of maximum sensitiveness of the indicating or recording instrument. The top part of the frame 22 carries a heavy lead block to give an initial load to the bellows assembly. The locking bolt 26 (fig.8b) permits the setting of the carriage 23 to be fixed. An H-strut 27 between the parts 22 and the head of the pendulum 18, together with the two adjustable drawbars 28 on each side of the yoke 19, increase the rigidity of the stand.

The thrust measuring device consists of a bellows assembly 29 filled with a non-compressible liquid. A thrust transmitted to

/the

the bellows causes the pressure in the liquid to rise and thus a simple pressure gauge can be used to indicate and measure the force acting on the bellows, which is linearly dependent on the thrust of the rocket motor.

This arrangement has been found very sensitive since there are no sliding parts such as pistons etc., which might cause errors in measurement owing to unknown friction effects. In order to avoid exposure to forces other than those transmitted by the thrust bolt 24, which mainly arise when moving the thrust measuring device into a different position, a cylindrical casing 30, connected to the carriage 23, can be joined to the bottom plate of the bellows assembly by the ring nut 31. For this purpose the bottom end of the casing 30 is threaded; the ring nut 31 has a plain cylindrical end which fits into a spigot on the bottom plate of the bellows assembly, and when screwed upwards the ring nut comes off the cylindrical guide and thus allows free movement of the bellows. But if it is screwed downwards it comes to rest on the bottom plate and a further movement lifts the thrust bolt 24 from the bellows assembly. The transmission of the thrust then takes place from the carriage 23 through casing 30 and the ring nut 31 directly to the top side of the cross slide. The thrust measuring device is thus put out of action, as is desirable when no thrust measurement is required, or when assembling of equipment on the stand threatens the sensitive bellows. In the latter case it is essential to block the movement of the pendulum. This can be done with a C-shaped clamping device 32 which is supported in the frame 22. By turning the spindle 33 the pendulum is fixed to the cross slide and a lock nut 34 allows it to retain that position.

The bottom plate of the bellows assembly is provided with a rectangular groove which fits closely in a key 35 connected to the top of the cross slide. Thus the bellows is kept in the correct position when being moved to alter the lever arm "A".

The pendulum support is mounted on the cross-slide III (figs.6a and 6b) which is shown in greater detail in figs. 8a and 8b. Two of the three movements required, i.e. the movement parallel to the axis of the motor and the traversing movement in the same horizontal plane can be carried out with it. The cross slide consists of the upper slide 36 for the axial movement and the bottom slide 37 for the traversing movement. The slide for the axial movement is driven by a handwheel on the control panel (fig.5). The movement is transmitted over a shaft with several universal ball joints and two bevel gears 39 and 40 to the spindle 38 which is supported by two self-aligning ball races, while the movement of the traversing slide 37 is controlled on the stand itself by the handwheel 41 and the spindle 42. If required, both movements can be locked with the clamping bolts 43 and 43a. Adjustable Vernier rings 44 on the handwheels allow the travel of the slides in both directions to be adjusted to a tenth of one revolution, i.e. 0.01", which is sufficiently accurate for all the measurements envisaged.

The cross slides with the pendulum support rest on a cylindrical column 45 which slides in a casing 46 and allows vertical adjustment of the motor. The movement of the sliding column is carried out from the panel by turning a handwheel (see fig.5) which drives a shaft with several universal ball joints. The movement is transmitted over the bevel gear 47 to the spindle 48. A double thrust bearing 49 carries the total weight of the movable parts of the stand and ensures absence of play in the vertical adjustment. The casing 46 itself is rigidly mounted on the grating of the proofstand. A general view of the stand as set up is given in the figs. 18 and 19.

/5.

5. DESIGN OF ROCKET MOTORS.

The general design principles of the small rocket motors have already been laid down in Section 2.3. In conformity with these ideas two rocket motors have been designed and will now be discussed.

"Rocket Motor I", which is shown in fig.9. is of a pattern which has been used with success in previous rocket research (see ref.1). The main design data are :-

normal combustion chamber pressure	20 ats.
maximum " " "	40 ats.
thrust	30 lbs.

In order to secure complete combustion the dimensions of the combustion chambers were made rather large for the small propellant throughput, the internal diameter being 1.575" and the length 4.7".

The combustion chamber consists of an inner copper liner 1 with helical grooves on its outer surface to ensure the forced flow of coolant. Near the expansion nozzle this liner is screwed tightly into an anodised light metal casing 2, whilst a stuffing box 3 prevents a leakage of the coolant at the opposite end. This arrangement permits free expansion of the liner 1 in the casing 2 which is at a lower temperature. Through connectors 4 situated at both sides of the combustion chamber the coolant is led into and brought out of the cooling channels (see fig.10). Provision (5 in fig.9) for measuring the combustion pressure is made at the entry to the expansion nozzle.

The fuel is led into the combustion chamber through a cylindrical injector holder 6 to a swirl nozzle 7, held in position by the connecting screw 8. The injector cap 9 and the holder 6 are screwed together tightly. The injection pressure for this type of injector is 10 to 15 ats. above the combustion pressure. Experience has shown that the atomisation obtained with this injector is not only very fine but that the droplet size is fairly uniform.

Oxygen is brought into the remaining annular space formed by the injector holder 6 and the reduced end of the liner 1. Before the entry into the combustion space this annulus is reduced further to a width of about .04" in order to increase the flow velocity and thus prevent flashback into the oxygen line. A flow velocity of about 120 m/sec. (400 ft/sec) has been found sufficient for that purpose. Four small spigots at the top end of the injector cap 9 serve to centre the injector and obtain a uniform width of the oxygen annulus.

The expansion nozzle consists of an inner copper part 10 surrounded by a bronze ring 11 made in two halves, which are brazed together after assembly. Grooves are cut in the inner surface of the part 11 to guide the coolant with the required velocity. The coolant is brought in and led out through connections at each side of the nozzle (see figs.11 and 12). With the help of the flange ring 12 and eight studs 13, the nozzle is connected to the combustion chamber. Fig.11 shows an expansion nozzle assembled in its casing and fig.12 without it.

Three nozzles were designed and constructed having throat diameters of 0.449", 0.325" and 0.232". The corresponding combustion chamber pressures, for constant propellant throughput, are 10, 20 and 40 ats. respectively.

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For many experiments on fundamental problems connected with high pressure combustion, the variation of certain characteristic sections of the motor are an absolute necessity. Hitherto this problem has been solved by building the required number of different rocket motors each designed for one specific purpose only. This method is not only expensive but also severely limits the number of possible variations. It seemed desirable to try another approach by separating the motor into a number of characteristic sections with all the parts freely interchangeable.

The first step to the realization of this idea was the design of the rocket motor RM.II which is shown in figs. 13 to 17. The entire motor was divided into the following main sections:

Expansion nozzle
Combustion chamber
Injector for oxygen
Injector for fuel

This allows a far reaching interchangeability and range of possible variations not only of expansion nozzles and injection systems but also of the combustion chamber itself. Combustion chamber sections of different lengths and diameters can be combined to form a unit as required.

For practical reasons the expansion nozzles developed for the motor RM.I will be used for this motor too, and the flange dimensions on the combustion chamber are designed accordingly.

The combustion chamber consists, as before, of an inner copper liner 1 which is screwed into the anodised light metal casing 2. Spiral grooves on the surface of part 1 ensure forced flow of the coolant. The inner dimensions of the combustion chamber, i.e. diameter and length are the same as for RM.I. The coolant enters the combustion chamber through the connector 3 and is brought first into an annular space between the liner 1 and the casing 2. From there it flows through the rectangular cooling channels to a flow guide ring 4 situated at the injection end of the chamber. This ring 4 is designed so as to permit the flow to the following cooled section with a minimum of friction and shock losses. Fig.15 shows a rear view of the combustion chamber of RM.II with the guide rings 4. A pressure connection 5 is provided at the end of the combustion chamber for measuring the combustion chamber pressure.

Gaseous oxygen is led into the oxygen injector (fig.16) through two unions 6. It then enters a distributor chamber from where it flows into the combustion chamber through 18 holes of .04" dia. These holes 8 are drilled tangentially (see fig.13 section BB) and are arranged in two planes in three groups of three holes each, giving opposite swirls in each plane. A good distribution of the gas and good mixing with the fuel is presumed to occur with this type of injector. The surface is water cooled. Cooling water is led from the guide ring 4 of the combustion chamber through three helical channels 9 (see figs. 13 and 16). The whole injector is made of several copper parts which are brazed together.

The fuel is fed through the union 10 into a distributor space 11. Four symmetrically arranged swirl nozzles 12, which are held in position and pressed against the injector plate 13 by two flat springs 14, inject the fuel into the combustion chamber.

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The surface of the injector plate 13 is cooled by water which has already passed through the cooling channels of the combustion chamber and the oxygen injector. Guide vanes 15 at the entry (see fig.17) permit the coolant to enter an annular ring space 16 which is formed by the injector plate 13 and the casing 17. Four holes 18 drilled radially and situated between the swirl nozzles lead the coolant to a central connector and through the banjo coupling 19 into the exit line.

The oxygen and fuel injectors are screwed together by means of the studs 20. The fuel distributor space 11 is closed by a cover plate 21 which contains a self-sealing U-shaped rubber ring 22 to seal from the fuel, and a stuffing box 23 to seal the water exit line. A small drainage hole 24 indicates possible leakages and, at the same time, prevents mixing of the fuel and the cooling water which are at this point under very different pressures.

6. EXPERIENCE WITH PROOFSTAND "A".

The proofstand "A", which is described in this report, while incorporating many of the features of the other proposed proofstands, was specifically designed for work on attenuation. For this reason the motor is not enclosed and is placed in the centre of a large bay in order to minimise reflection effects of the radiation.

To date, 80 runs with a total operating time of about 160 minutes have been carried out satisfactorily. The longest run has been 5 minutes at a combustion pressure of 10 ats. During such long runs the operating conditions have remained constant, no adjustments being necessary. In other experiments, runs have been started and stopped over a period of two hours without altering the setting of the controls.

In the early runs carbon dioxide was used as the pressurising gas as it is supplied in liquified form and thus for a given cylinder capacity the total gas volume obtainable was much larger. Secondly, it was intended to use carbon dioxide in a fire extinguishing circuit. The pressure obtainable from the cylinders depends markedly on the ambient temperature, and because of this, was found inadequate in winter. It was also observed that during the flushing of the lines, rapid adiabatic expansion of the gas led to formation of solid carbon dioxide with a subsequent blockage and failure of valves. The ignition fuel absorbed large quantities of carbon dioxide which led to difficulties in handling, for on releasing the pressure on the ignition fuel cylinder the dissolved gas came out of solution suddenly and ejected ignition liquid through the release valve. For these reasons nitrogen is now used as pressurising gas.

Apart from these difficulties and the action of zinc-diethyl on the seatings of valves (minimised by adequate flushing), the equipment has functioned as planned and no major alteration has been necessary.

Both rocket motors, RM.I (fig.9) and RM.II (fig.13), have been tested and each has behaved satisfactorily. Although most of the runs have been carried out with RM.I, there have been a sufficient number of long runs with RM.II to prove the usefulness of the design. Fig.20 shows the proofstand "A" during a run with rocket motor RM.I at 10 ats. combustion pressure; fig.21 gives a close-up view of rocket motor RM.I during operation at the same pressure.

/The

The general arrangement of the components of proofstand "A" is shown in figs. 18 and 19.

7. FUTURE DEVELOPMENTS.

The favourable experience obtained with the first miniature proofstand "A", fully justified the earlier decision to erect three more proofstands of this type.

Although there was every reason not to change the principles of the layout, it seemed desirable for fundamental work on spectroscopy, heat transfer, radiation etc., to widen the possible field of application by adding to the liquid fuel circuit a second independent circuit for gaseous fuels, such as hydrogen, carbon monoxide, methane, etc.

As these gases are taken from large high-pressure gas cylinder batteries, with an initial filling pressure of over 180 ats., it will be possible, with the existing valves and control units in the gas circuits, to increase the combustion chamber pressure to well over 100 ats. Furthermore, the total running time, which was previously limited by the size of the liquid fuel cylinder, can be increased as desired up to about 30 mins.

The addition of another fuel circuit, and the experience gained so far, call for a modified ignition circuit. It will be completely independent of the fuel circuits. There will be a separate nitrogen solenoid valve for pressurising the ignition fuel cylinder and a pneumatically operated feed valve to close the inlet into the combustion chamber.

Certain spectroscopic work requires the complete absence of adventitious impurities in the combustion gases which the use of zinc-diethyl as ignition fuel might introduce. Spark ignition is an alternative and suitable devices are being developed to prevent damage to electrodes after ignition has taken place.

All propellant lines, both for gases and liquids, will contain remote indicating flowmeters which will also allow ratio control of the two propellants. The cooling lines will have the same flowmetering arrangements, combined with adjustable minimum contacts on the instruments to perform the function of the pressure operated relay 37 in fig.4.

For runs with liquid fuels the rocket motors RM.I and RM.II will be used again, but a new injection system has been designed for gaseous fuels, in the first instance, for hydrogen.

Interesting new combustion chambers are now under development for certain basic investigations, e.g. a combustion chamber for heat transfer studies, a rocket motor for extremely high combustion chamber pressures up to 160 ats., and a combustion chamber with windows permitting direct axial optical observation of the interior of the combustion chamber during operation in order to study flow and mixing problems, properties of gases under high pressure and temperature etc. The windows will be fitted into a cooled rotatable cylinder so that they will only be in contact with the combustion gases during the time required for observation.

With these new proofstands and specially designed rocket motors research tools will be available for carrying out an extensive research programme on high pressure combustion.

/8. Bibliography.

8. BIBLIOGRAPHY.

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2)	M.v.Stein	Diagrams for the Entropy, the Enthalpy and the Composition of Oil-Oxygen Combustion Gases and their Application to the Rocket Motor, HEC-Transl. No. 10328.
3)	A.B.P. Beeton.	An Approximate Method for Estimating the Performance of Oxygen-Oil Rockets, R.A.E. Techn. Note No. Gas 31.

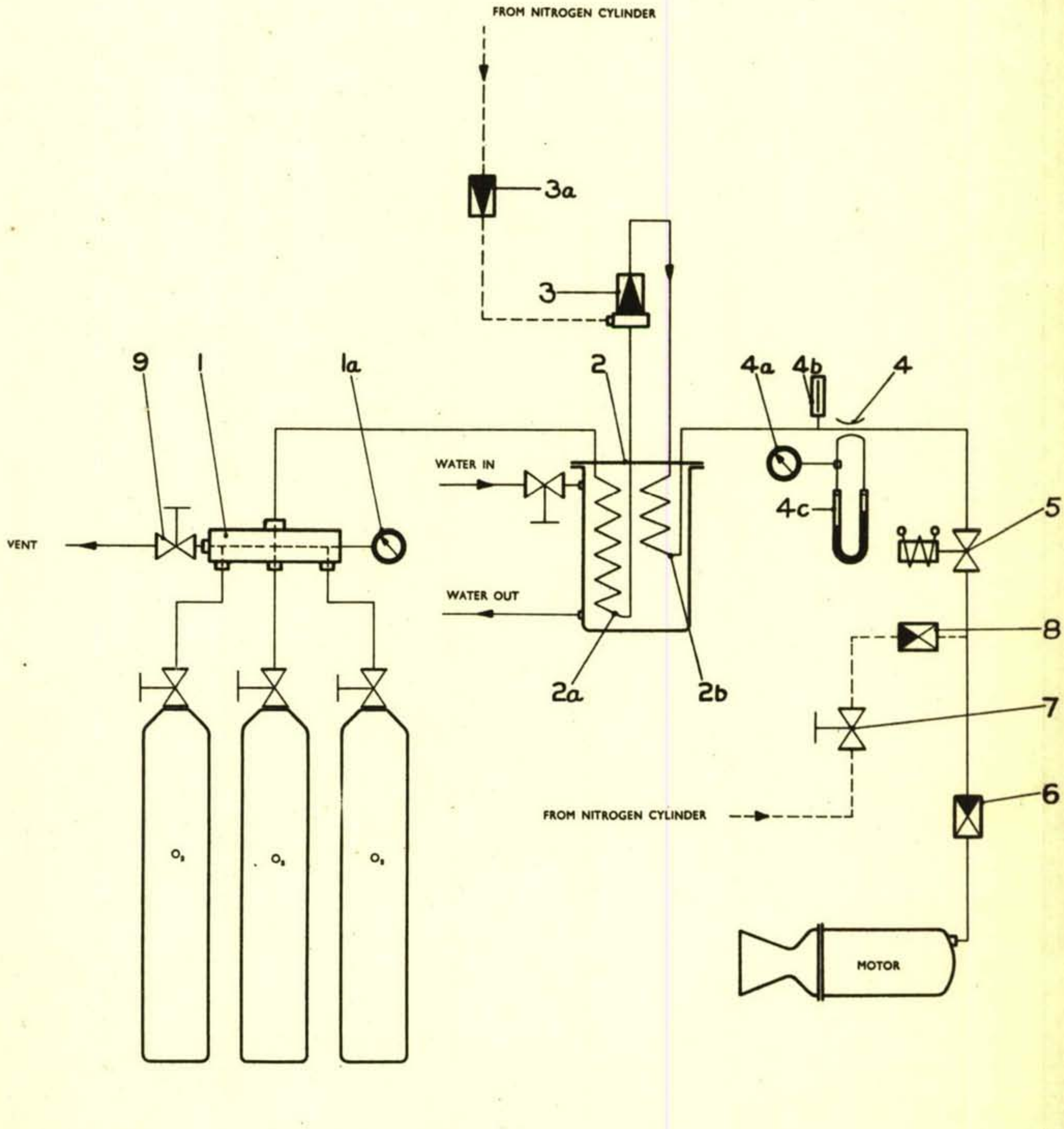

FIG. 1. OXYGEN CIRCUIT.

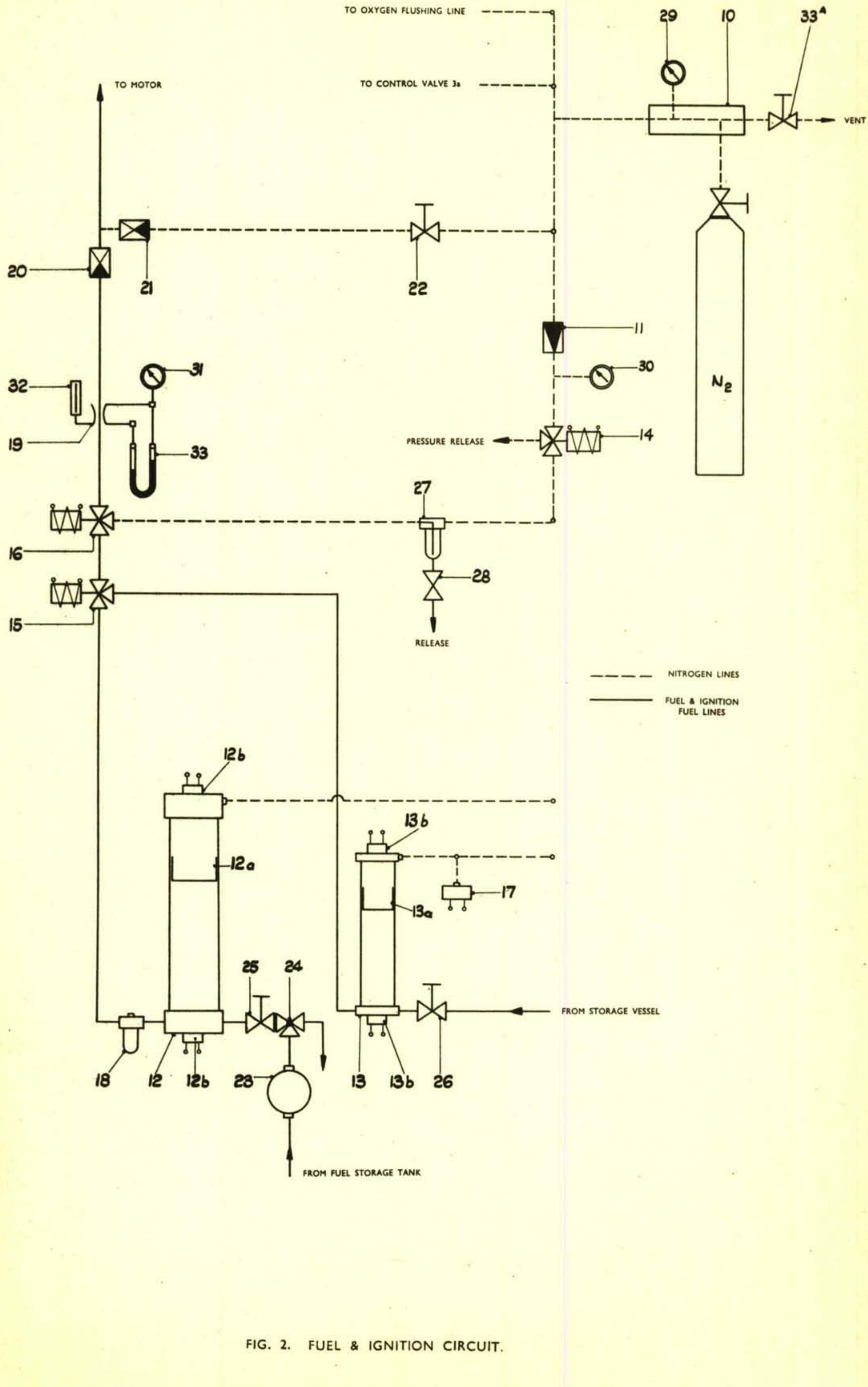

FIG. 2. FUEL & IGNITION CIRCUIT.

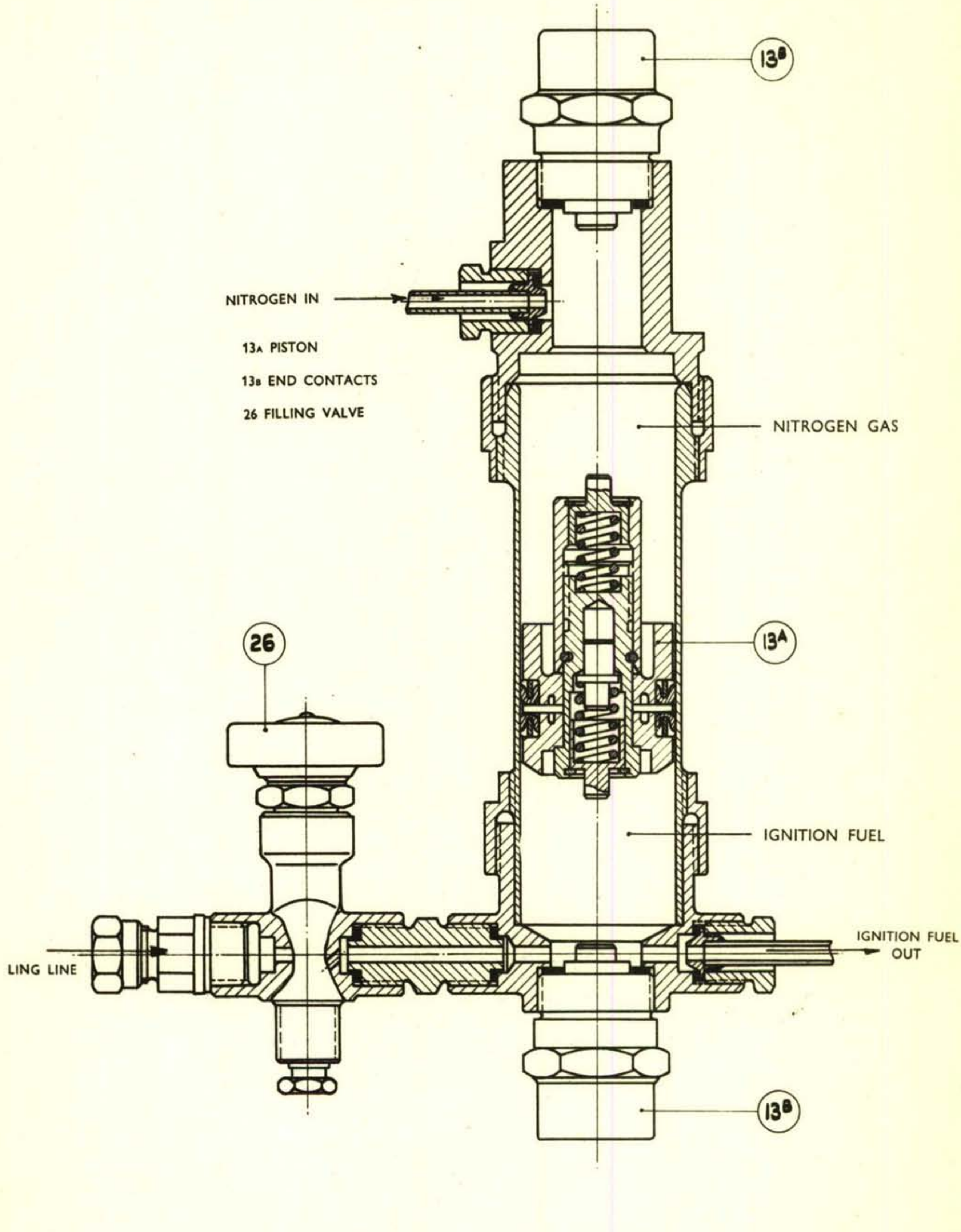

FIG. 3. IGNITION FUEL CYLINDER.

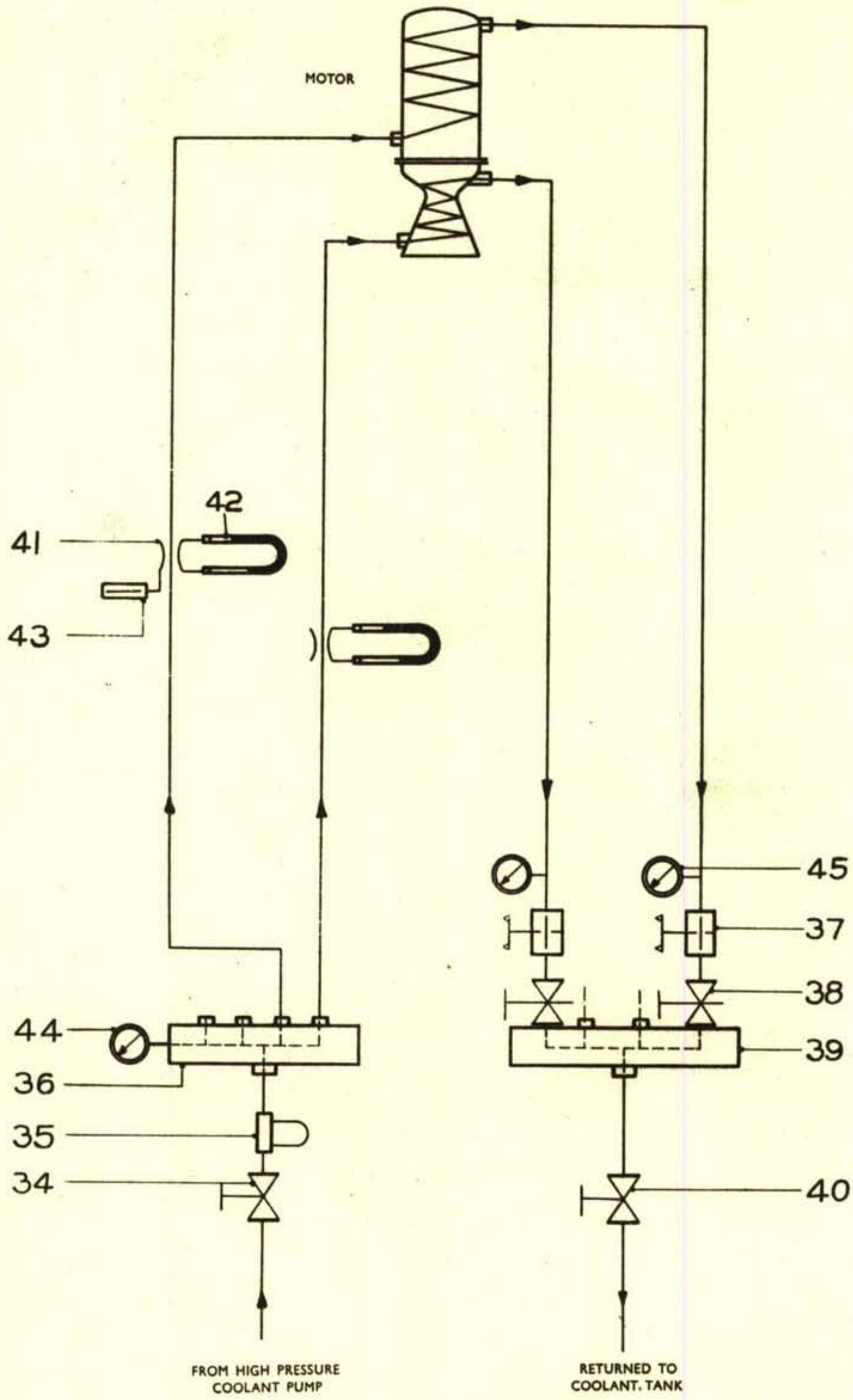

FIG. 4. COOLANT CIRCUIT.

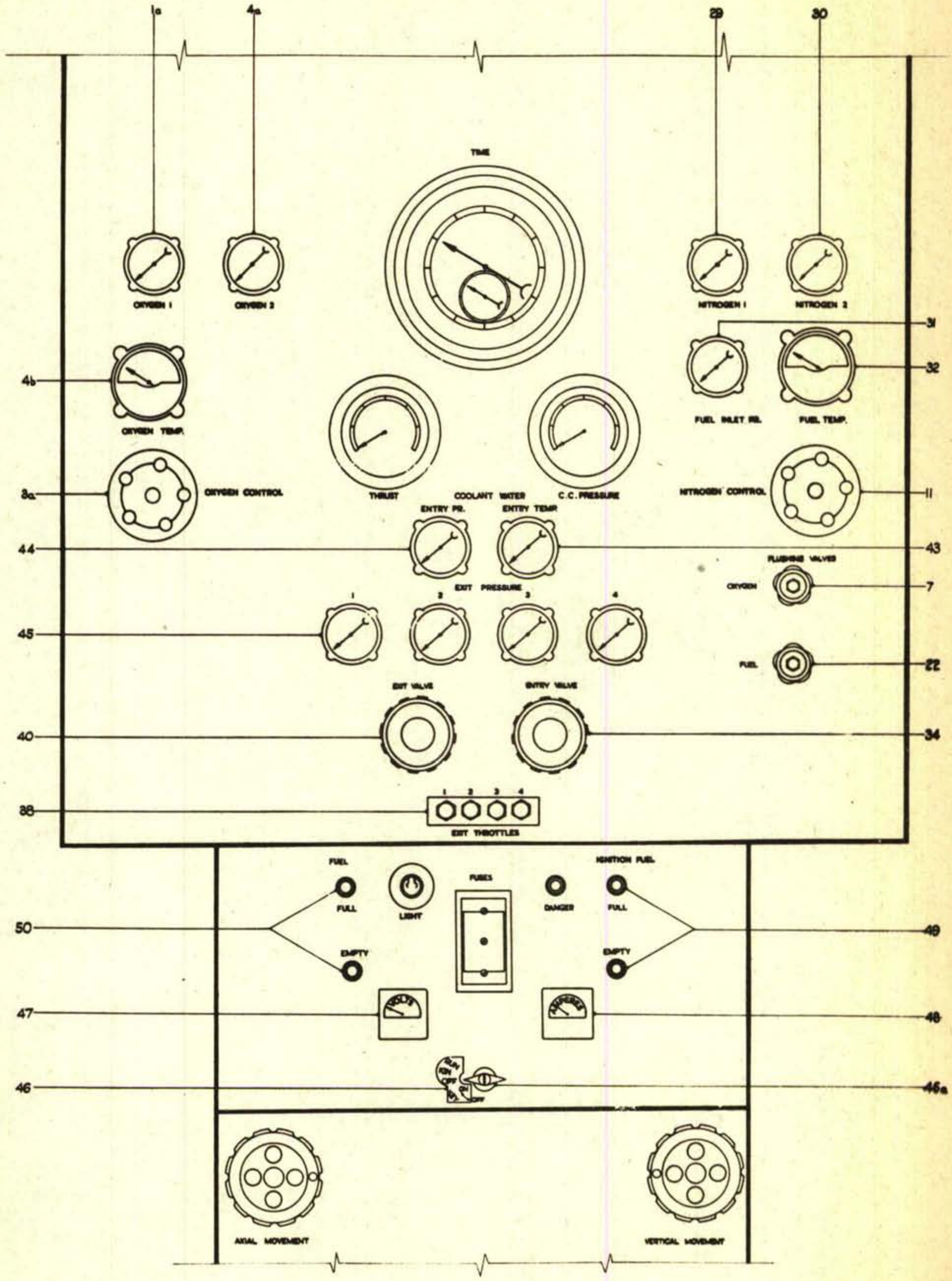

FIG. 5. ARRANGEMENT OF CONTROLS AND INSTRUMENTS ON CONTROL PANEL.

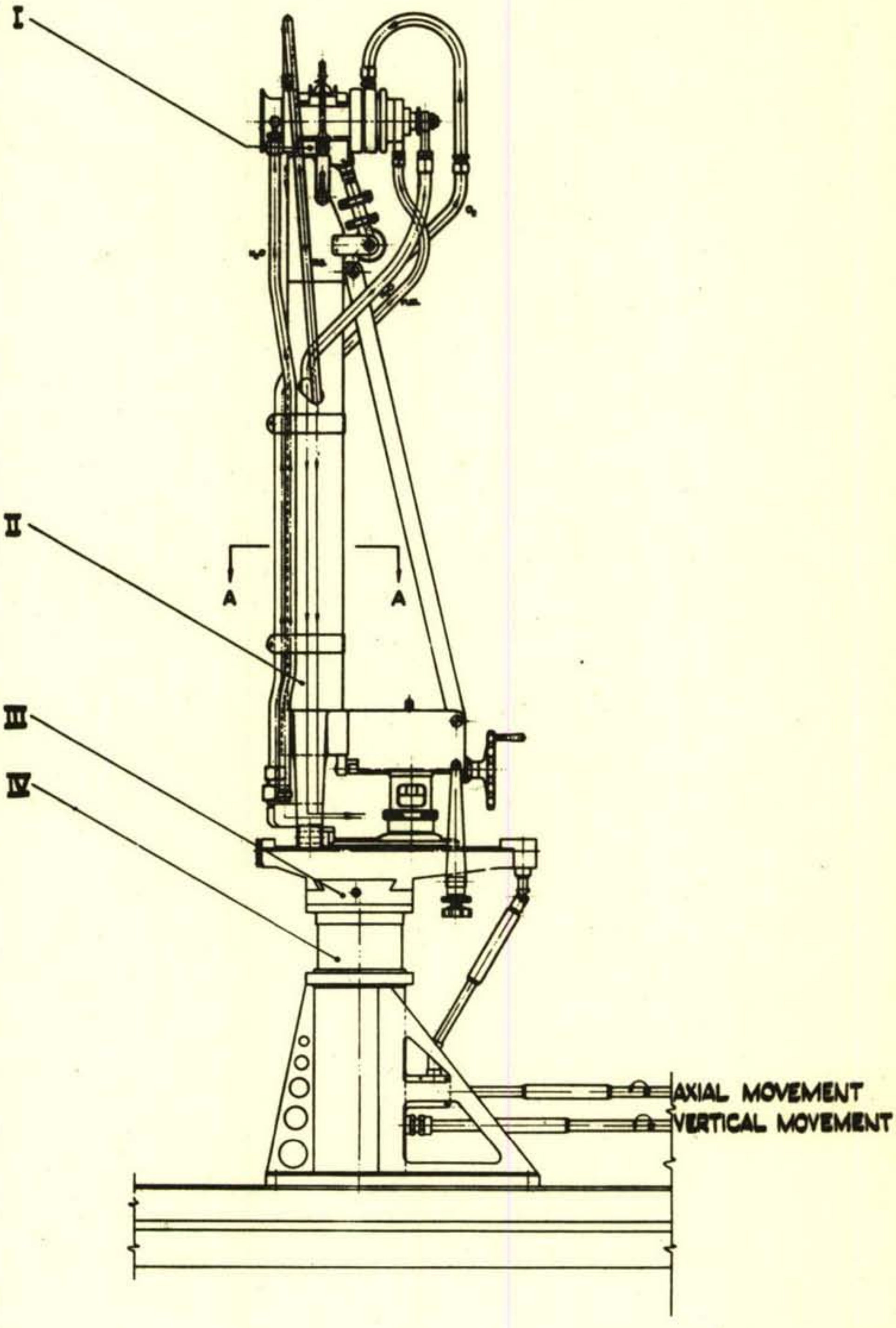

FIG. 6a. THREE-CO-ORDINATE ROCKET MOTOR STAND
FOR MINIATURE PROOFSTAND.

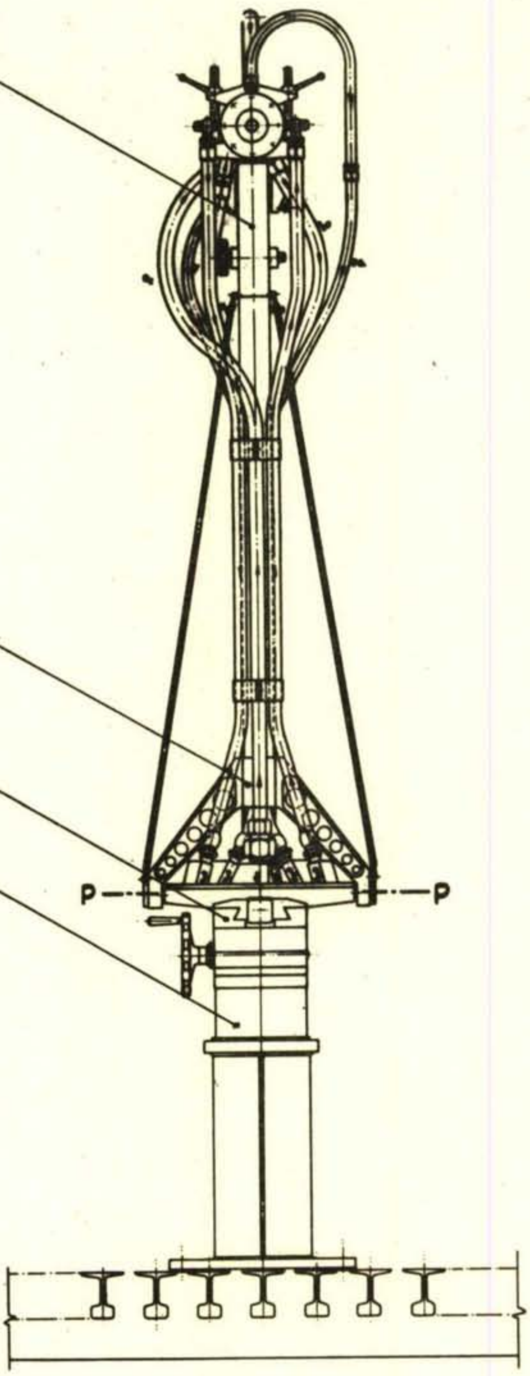

FIG. 6b. THREE-CO-ORDINATE ROCKET MOTOR STAND
FOR MINIATURE PROOFSTAND. END ELEVATION.

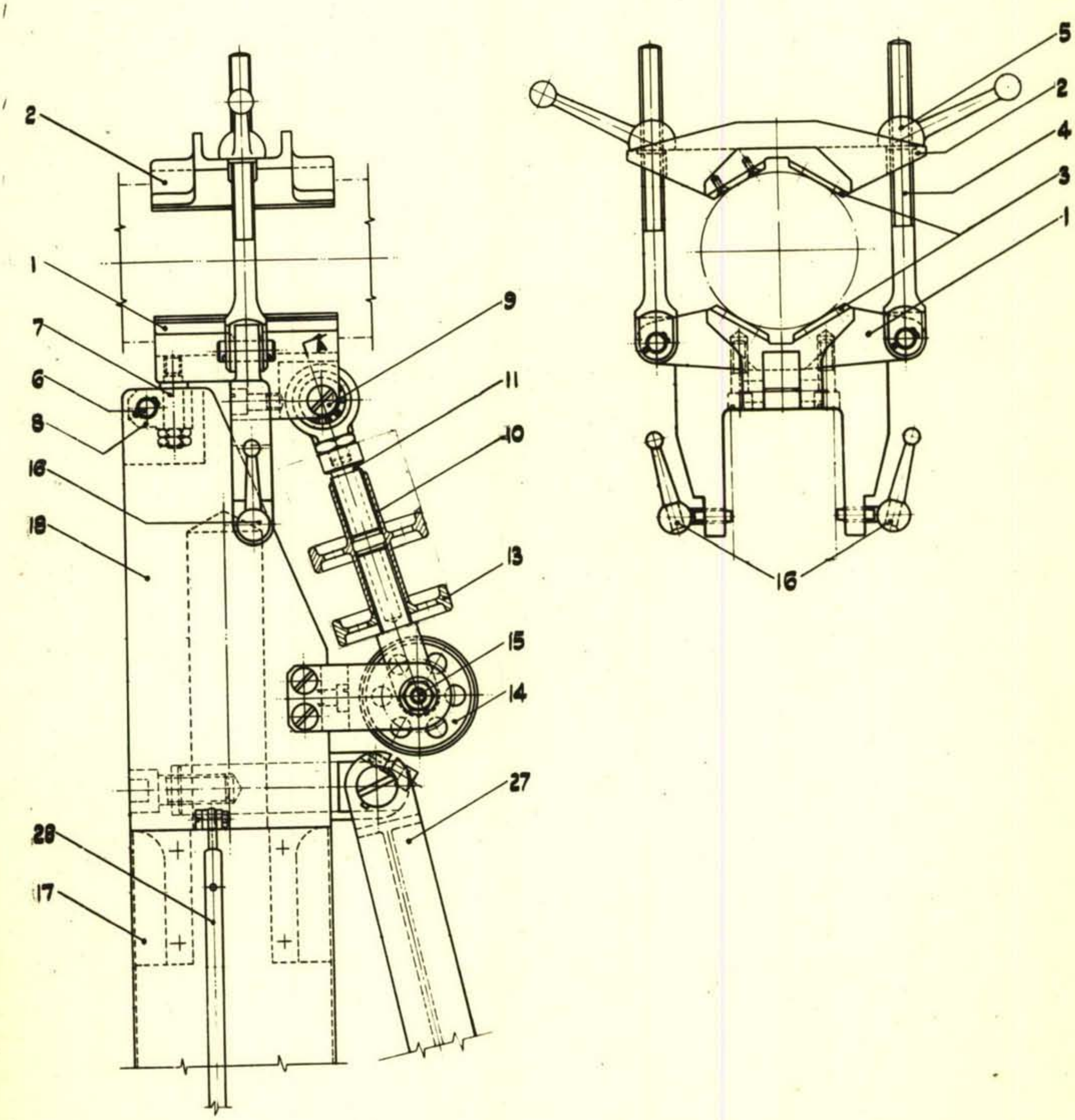

FIG. 7. ADJUSTABLE CLAMPING DEVICE AND HEAD OF PENDULUM SUPPORT FOR ROCKET MOTOR STAND.

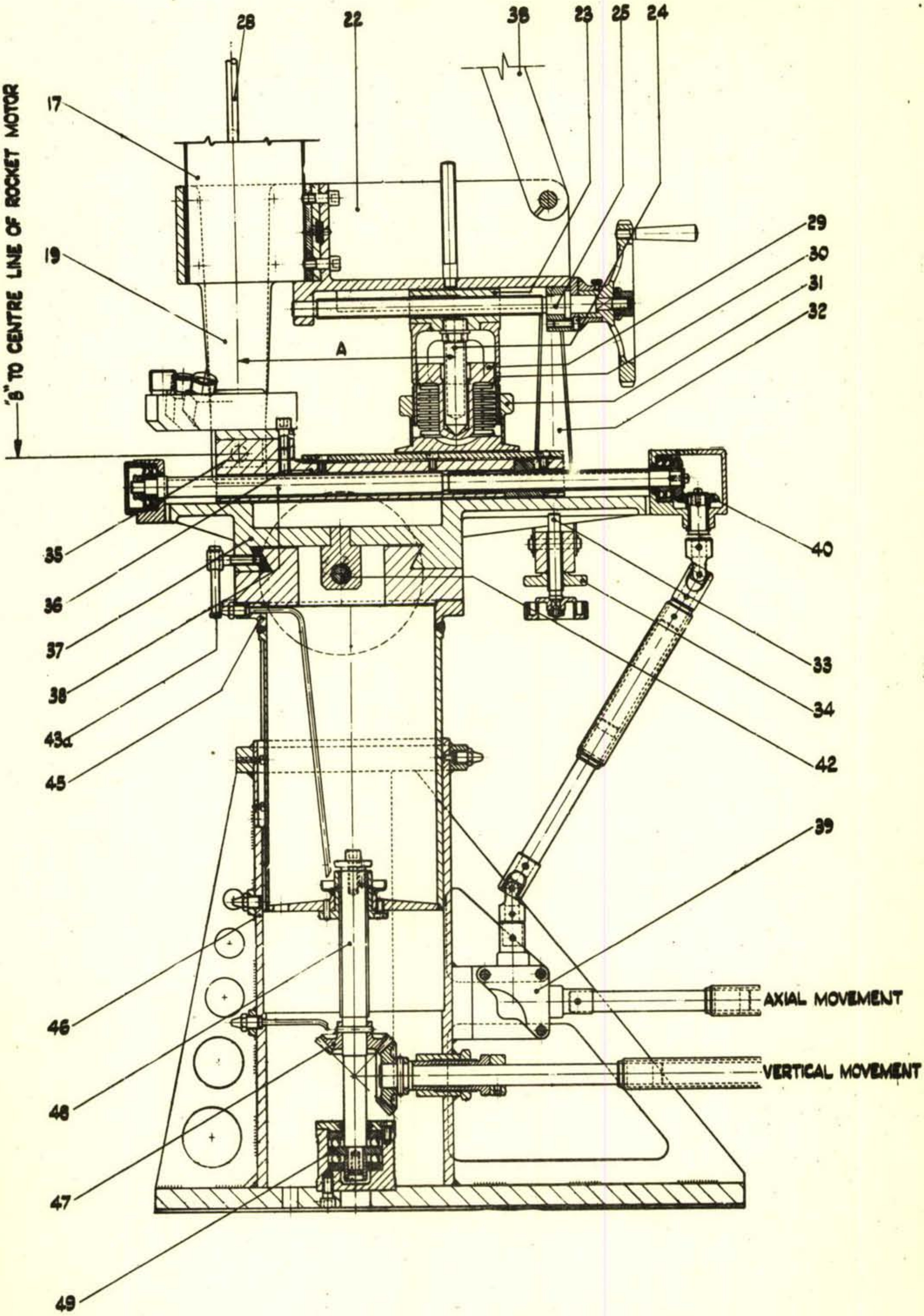

FIG. 8a. BOTTOM PART OF PENDULUM SUPPORT, CROSS SLIDES AND VERTICAL COLUMN.

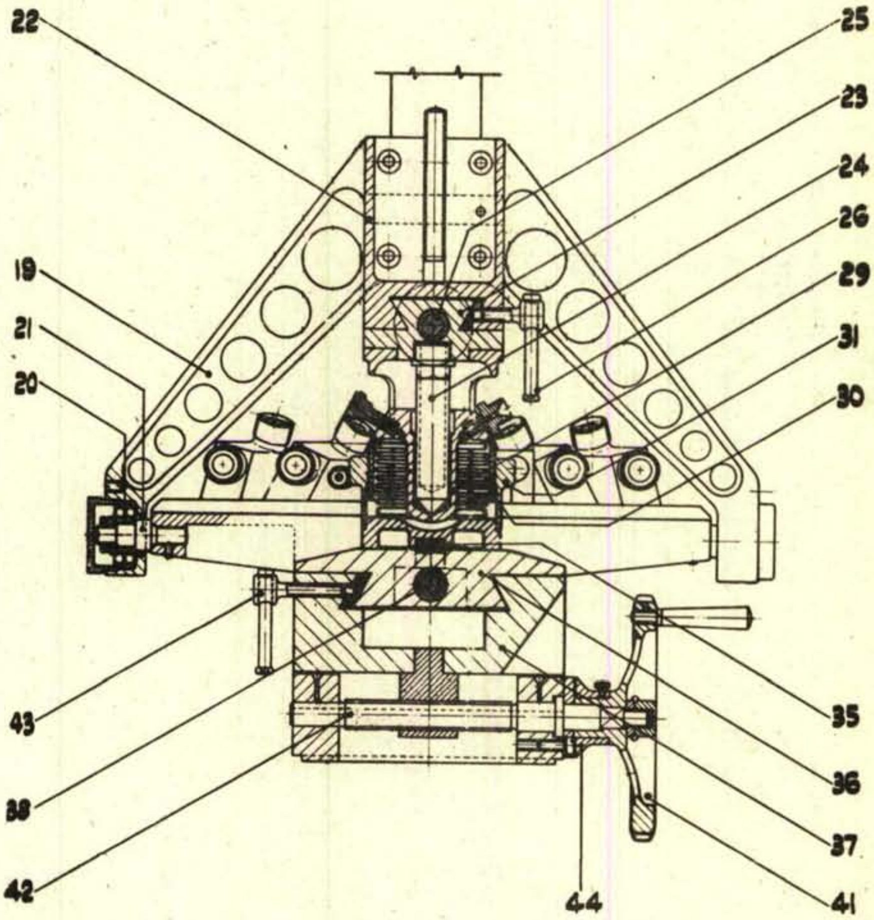

FIG. 8b. BOTTOM PART OF PENDULUM SUPPORT AND CROSS SLIDES.

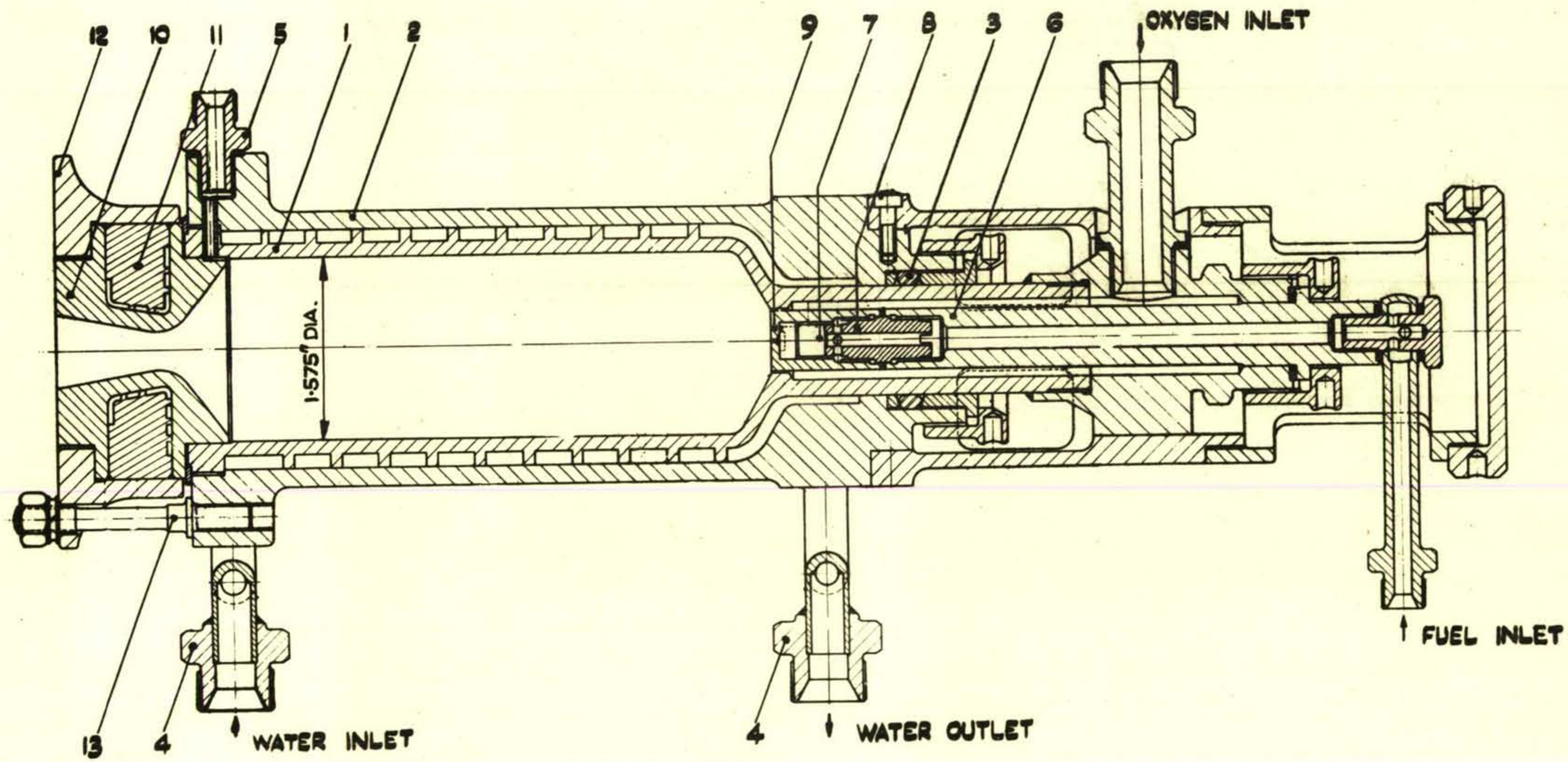

FIG. 9. EXPERIMENTAL ROCKET MOTOR. R.M.I.

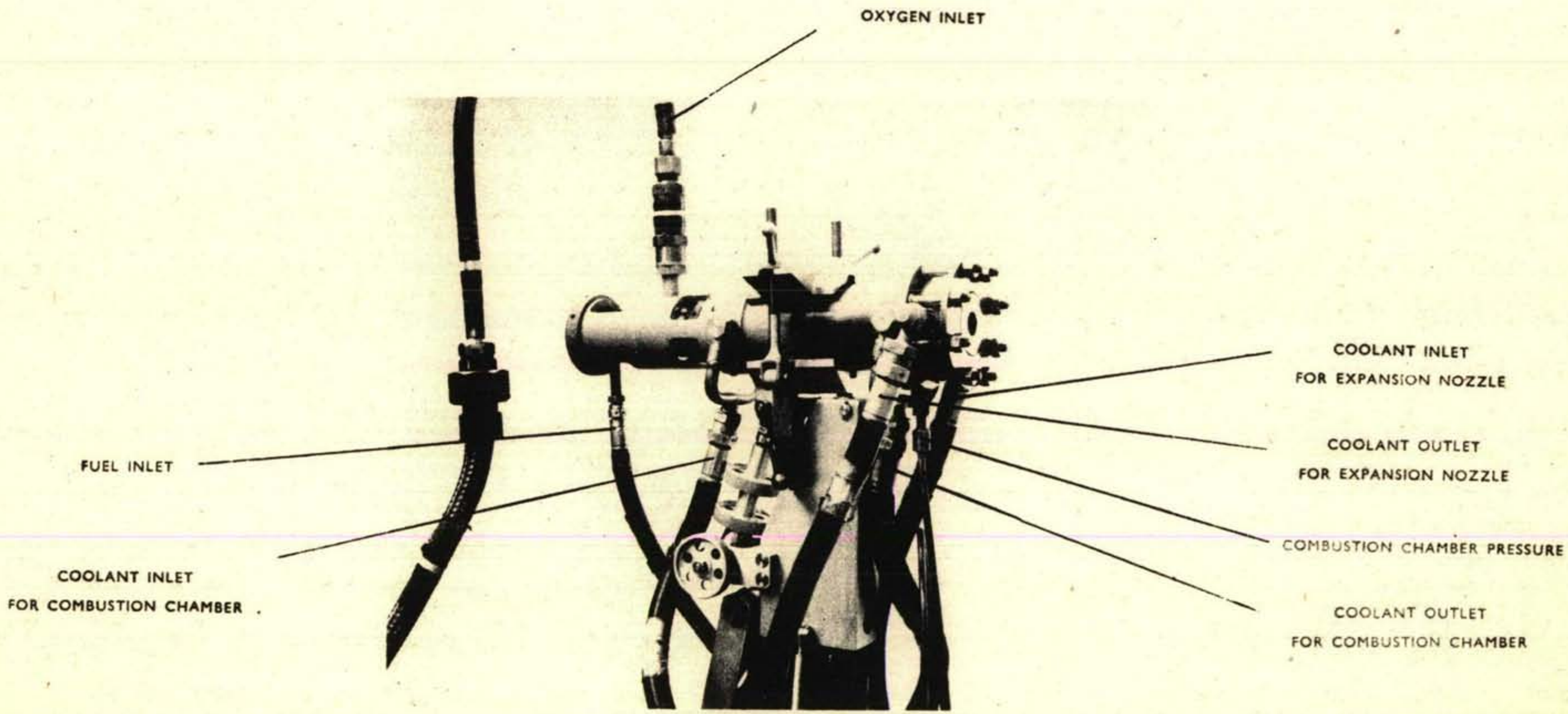

FIG. 10. ROCKET MOTOR R.M.I.
MOUNTED ON PENDULUM SUPPORT

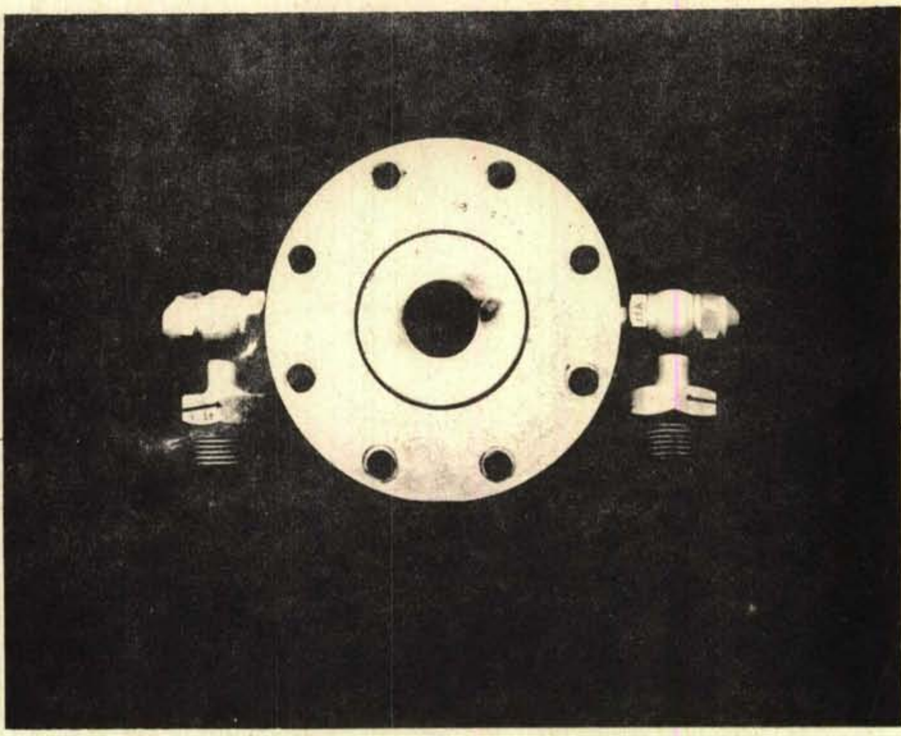

FIG. 11. EXPANSION NOZZLE
WITH CASING

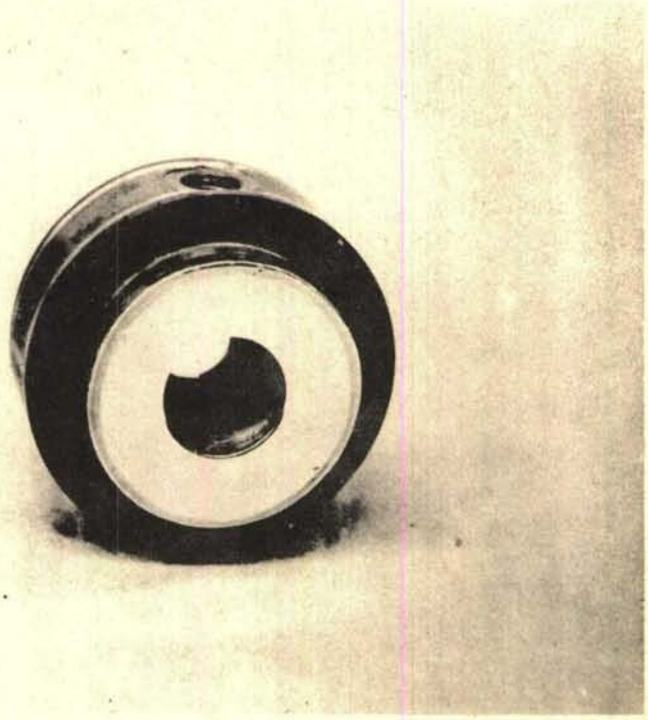

FIG. 12. EXPANSION NOZZLE
WITHOUT CASING

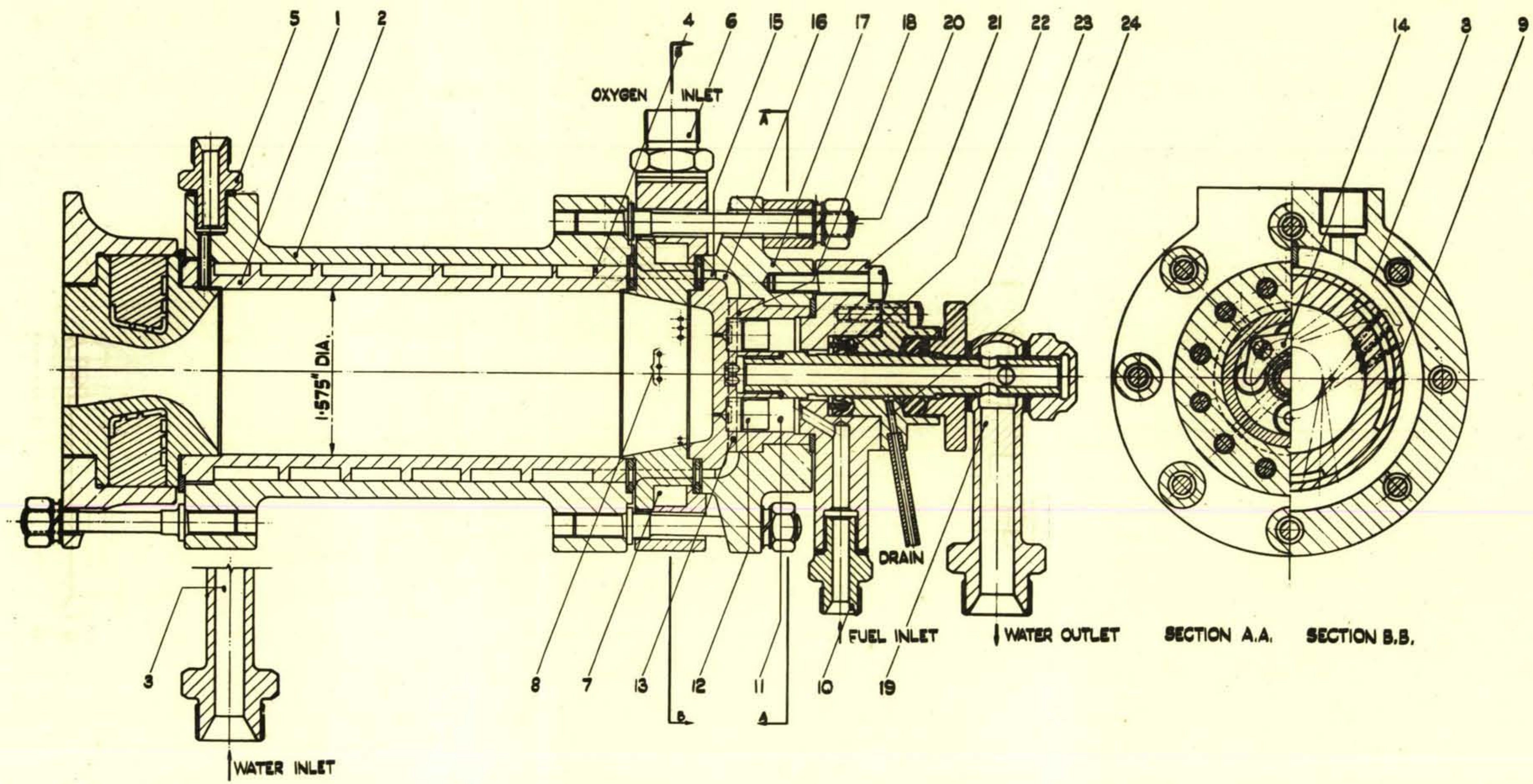

FIG. 13. EXPERIMENTAL ROCKET MOTOR. R.M.II.

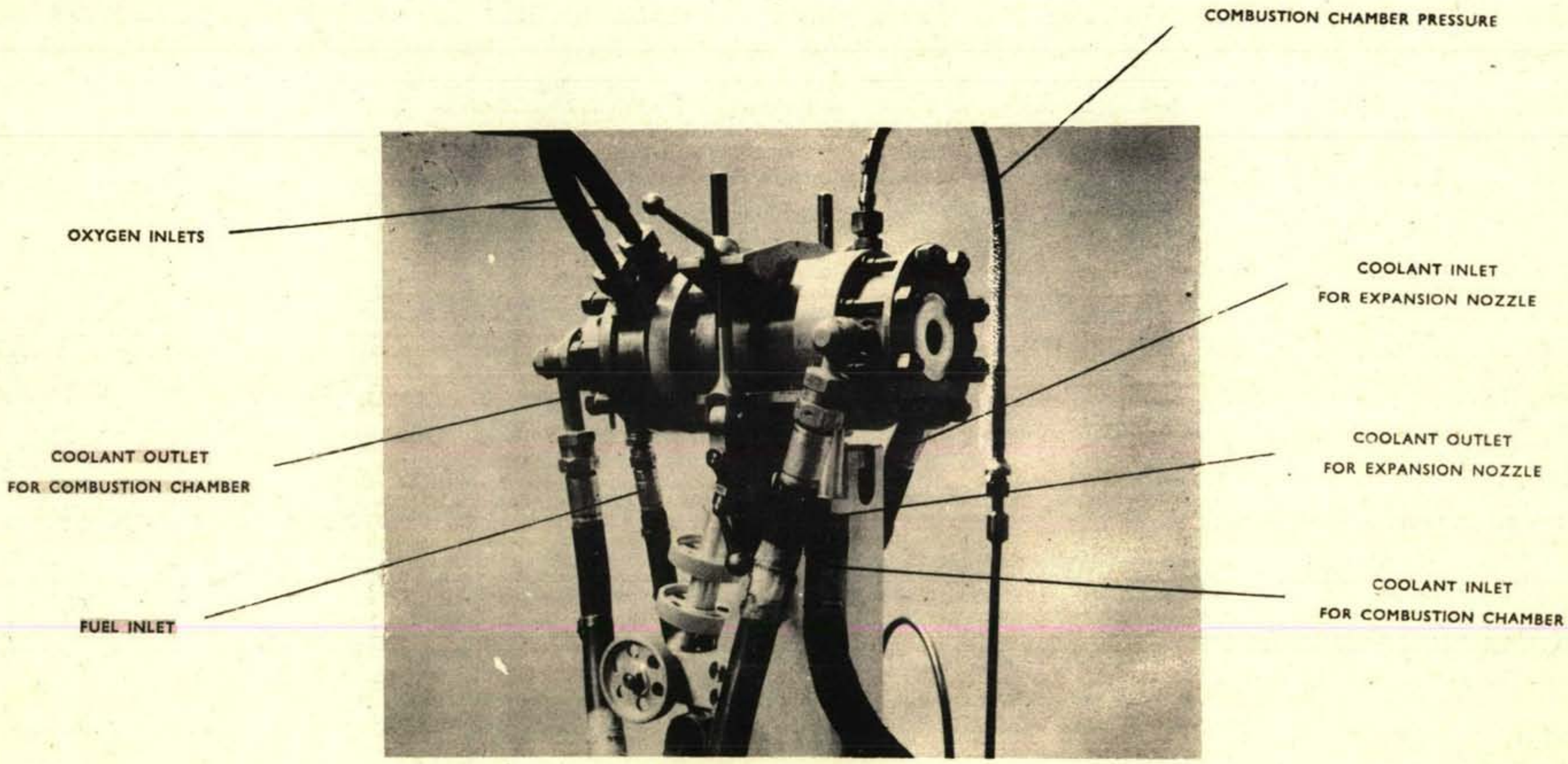

FIG. 14. ROCKET MOTOR R. M. II.
MOUNTED ON PENDULUM SUPPORT

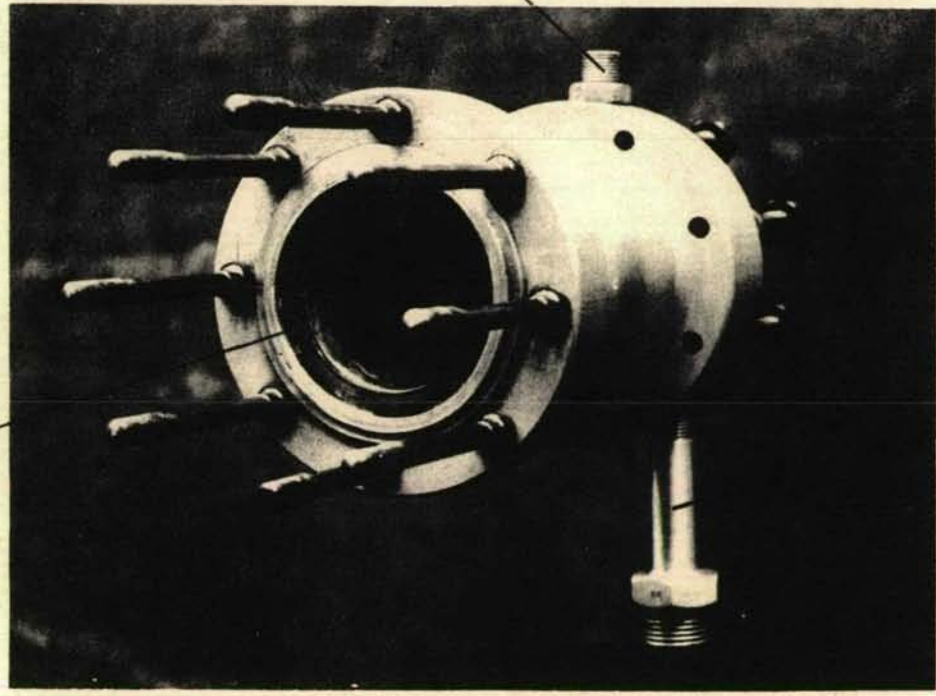

FIG. 15. COMBUSTION CHAMBER OF ROCKET MOTOR R.M. II.

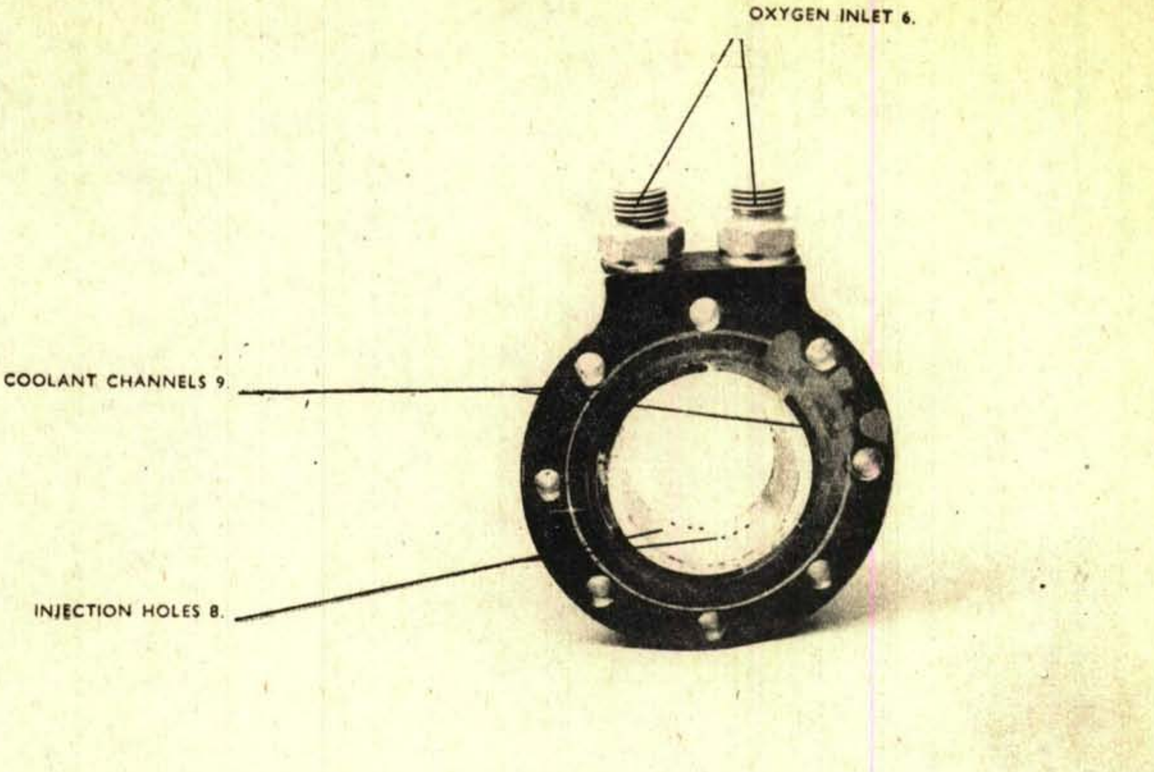

FIG. 16. OXYGEN INJECTOR OF ROCKET MOTOR R.M.II.

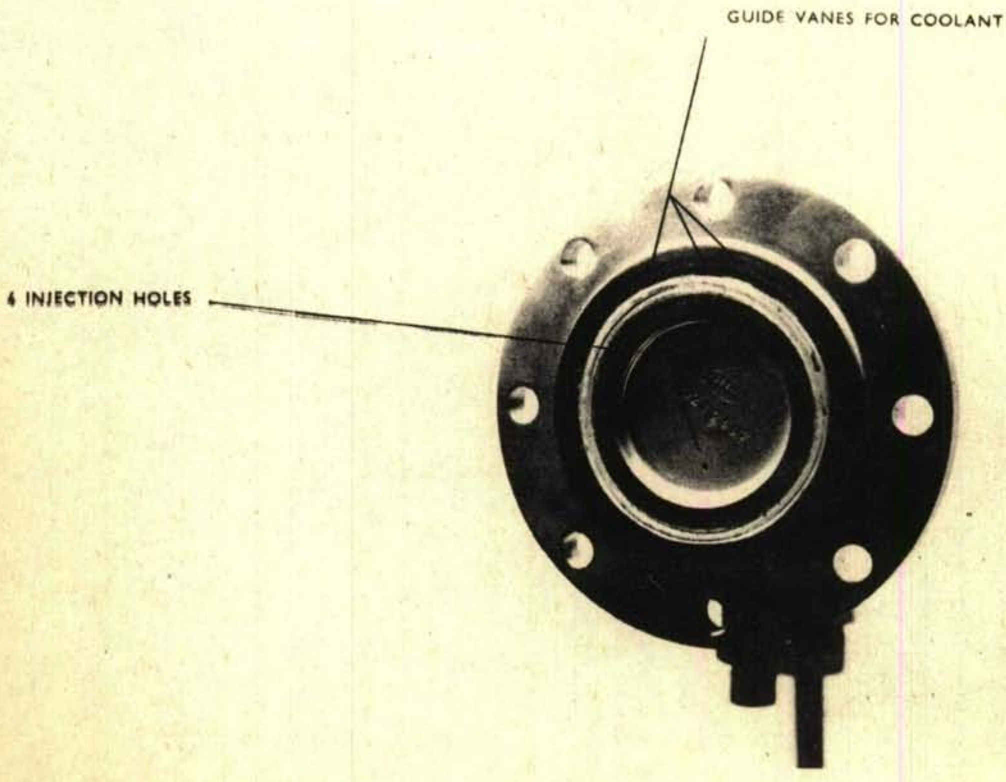

FIG. 17. FUEL INJECTOR OF ROCKET MOTOR R.M.II.

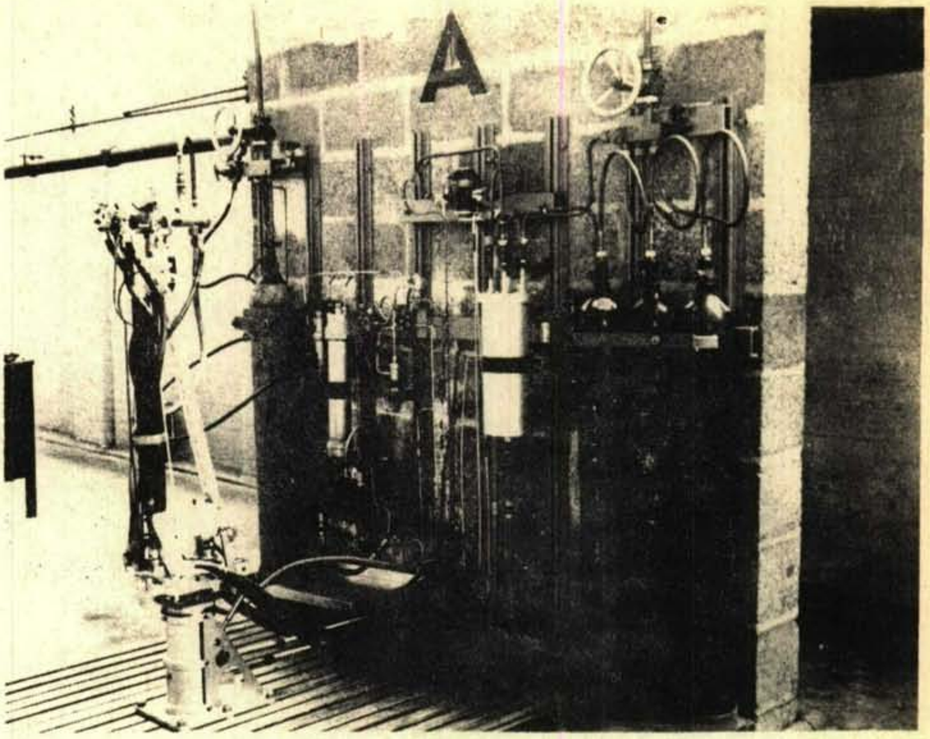

FIG. 18. GENERAL VIEW OF MINIATURE PROOFSTAND "A"

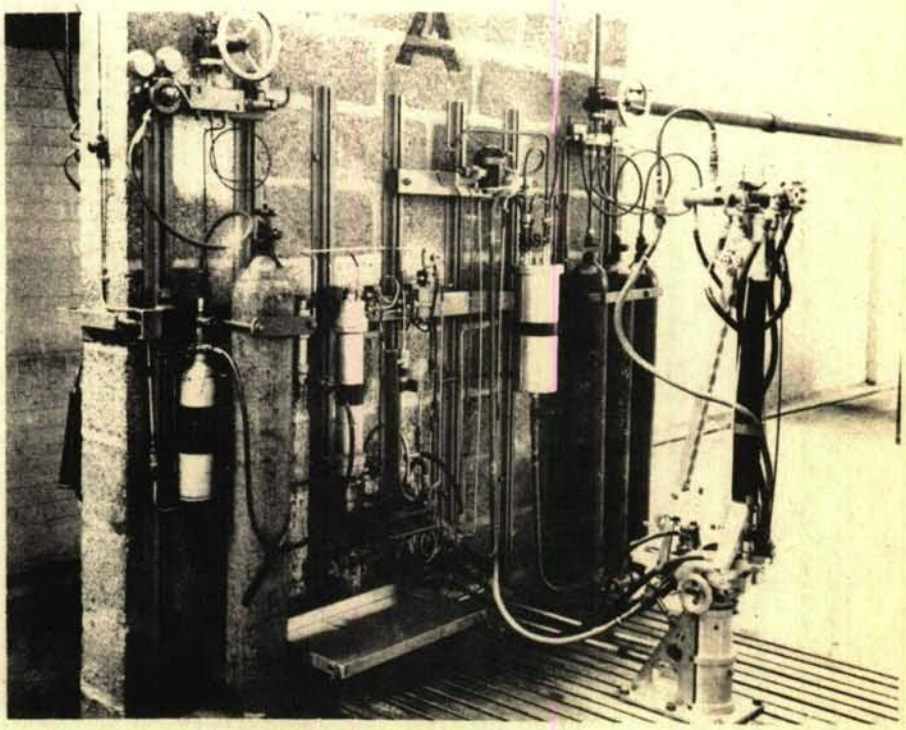

FIG. 19. GENERAL VIEW OF MINIATURE PROOFSTAND "A"

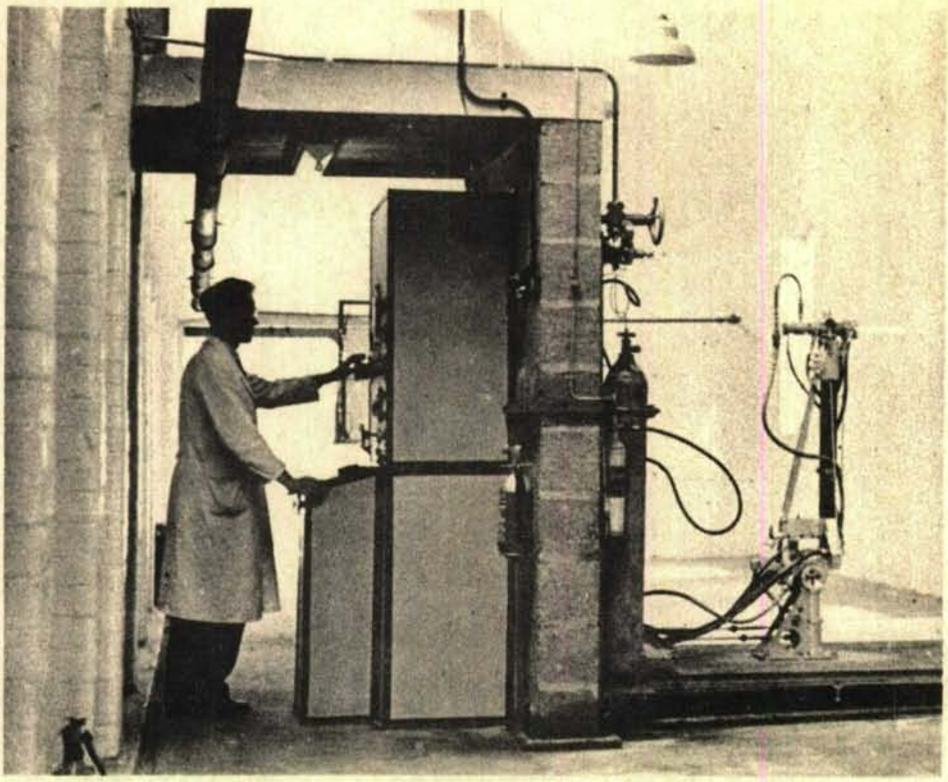

FIG. 20. MINIATURE PROOFSTAND "A"
DURING OPERATION

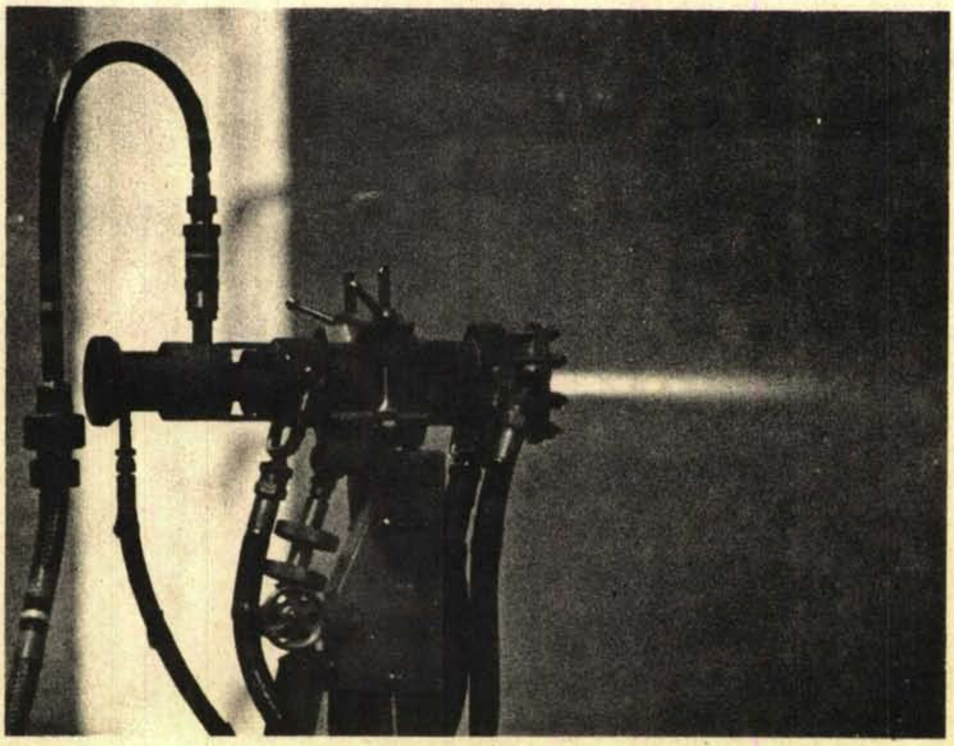

FIG. 21. ROCKET MOTOR R.M.I.
DURING OPERATION AT 10 ATS COMBUSTION CHAMBER PRESSURE